Column Databases

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Overview

- Column-oriented datastores
  - Concept
- Google BigTable
- Cassandra
  - Data Model
  - Cassandra query language
    - DDL statements
    - DML statements

Concept

- **Store and process data by column instead of row**

- Origin in analytics and business intelligence
  - usually consist of aggregation queries
  - operating in a shared-nothing massively parallel processing architecture to build high-performance applications
- Usually described as “sparse, distributed, persistent multidimensional sorted map”
- Main inspiration for column-oriented datastores is Google’s Bigtable

Store by Column vs Row

- Table example:

ID	name	address	zip code	phone	city	country	age
1	Benny Smith	23 Workhaven Lane	52683	14033335568	Lethbridge	Canada	43
2	Keith Page	1411 Lillydale Drive	18529	16172235589	Woodridge	Australia	26
3	John Doe	1936 Paper Blvd.	92512	14082384788	Santa Clara	USA	33

- Store by row:

```
1,Benny Smith,23 Workhaven Lane,52683,14033335568,Lethbridge,Canada,43;2,Keith Page,1411 Lillydale
Drive,18529,16172235589,Woodridge,Australia,26;3,John Doe,1936 Paper Blvd.,92512,14082384788,
Santa Clara,USA,33;
```

- Store by column:

```
1,2,3;Benny Smith,Keith Page,John Doe;23 Workhaven Lane,1411 Lillydale Drive,1936 Paper
Blvd.;52683,18529,92512;14033335578,16172235589,14082384788;Lethbridge,Woodridge,Santa
Clara;Canada,Australia,USA;43,26,33;
```

Store by Column vs Row

- Store by row:

ID	name	address	zip code	phone
1	Benny Smith	23 Workhaven Lane	52683	14033335568
2	Keith Page	1411 Lillydale Drive	18529	16172235589
3	John Doe	1936 Paper Blvd.	92512	14082384788

- Store by column:

ID
1
2
3

name
Benny Smith
Keith Page
John Doe

address
23 Workhaven Lane
1411 Lillydale Drive
1936 Paper Blvd.

zip code
52683
18529
92512

phone
14033335568
16172235589
14082384788

Columnar databases

- Good for
  - Queries that involve only a few columns
  - Aggregation queries against vast amounts of data
  - Column-wise compression

- Not so good
  - Incremental data loading
  - Online Transaction Processing (OLTP) usage
  - Queries against only a few rows

(Dis)Advantages explained…

- ↑ Some queries could become very fast
  - aggregation queries
  - function over fields, e.g. average age of users
- ↑ Better data compression
  - when running the algorithms on each column (similar data)
  - accentuated as your dataset becomes larger

- ↓ Aggregation is great, but some applications need to show data for each record
  - columnar databases are generally not great for these types of queries
- ↓ Writing new data could take more time
  - inserting a new record into a row-oriented database is a simple write operation
  - updating many values in a columnar database could take much more time

Different terminology?

- Column
- Column-family
- Wide-column
- We will look more into Column-family (Wide)
  - But will use "column-oriented database", for simplification

Data Model

- **Column family** (table)
  - table is a collection of similar rows (not necessarily identical)
- **Row**
  - row is a collection of columns
    - should encompass a group of data that is accessed together
  - associated with a unique row key
- **Column**
  - column consists of a column name and column value (and possibly other metadata records)
  - scalar values, but also sets, lists and maps

Usage

- Suitable use cases
  - event logging, content management systems, blogs, …
    - i.e., for structured flat data with similar schema
  - batch processing via map reduce

- When not to use
  - ACID transactions are required
  - Complex queries: joining, …
  - Early prototypes
    - i.e., when database design may change

Representatives Technologies

cassandra

APACHE HBASE

accumulo™

Google Bigtable

HYPERTABLE INC

Representatives Technologies

- Bigtable is the inspiration for column-oriented datastores

- Datastores influenced by Bigtable
  - Hypertable
  - HBase

- Cassandra is an extension of Bigtable with aspects of Amazon's Dynamo

Why Bigtable

- Internal Google database that kickstarted the NoSQL industry
- Web indexes behind search engine took too long to build
- Needed real-time access to petabytes of data
- 2006 research paper describing Bigtable
  - Led to HBase, Cassandra, and other NoSQL databases
  - Received the SIGOPS Hall of Fame Award
- Bigtable powers Gmail, Google Maps, and other services
- In 2015, Google made Bigtable available as a service

https://www.youtube.com/watch?v=1qieV-WCU_w
https://www.usenix.org/legacy/event/osdi06/tech/chang/chang.pdf

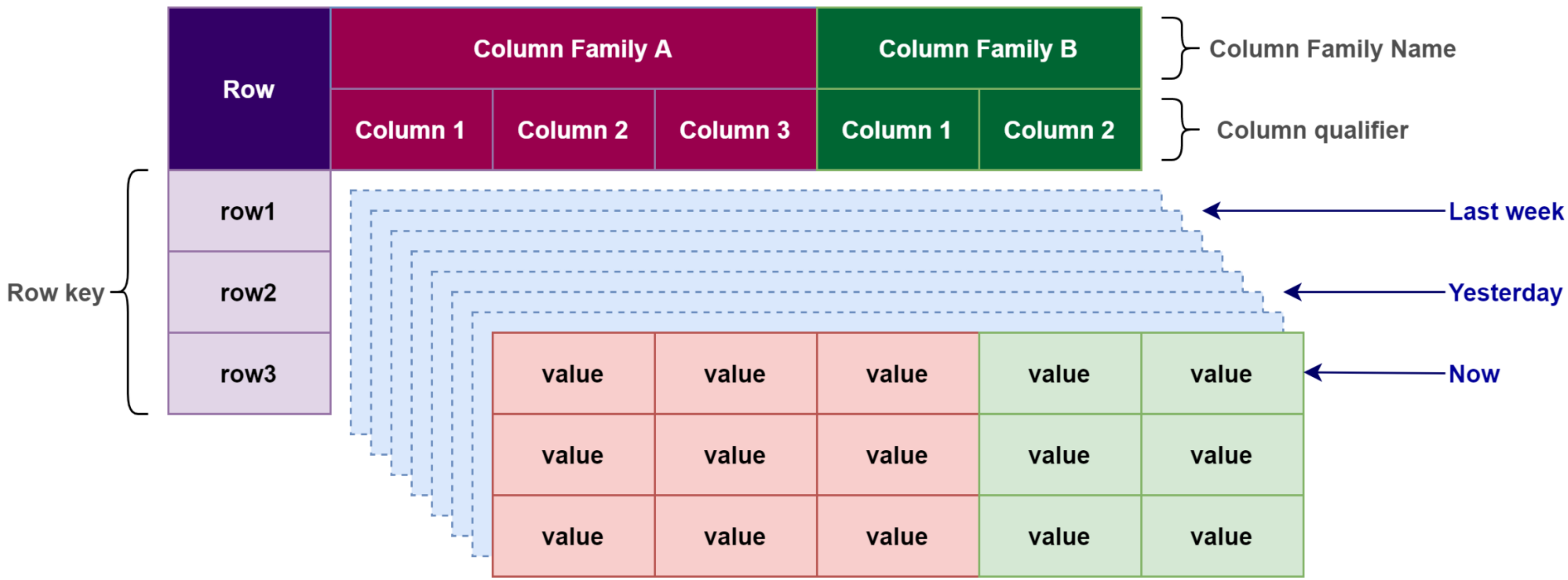
BigTable Data Model

- Distributed multi-dimensional sparse map
- Map is indexed by a row key, column family, column key and a timestamp

  (Row, Column, Timestamp) -> Cell contents
- Row keys are arbitrary strings
- Row is the unit of transactional consistency

```
{ row : {
        column_family :  {
                column : {
                   timestamp : value
                }
          }
}
```

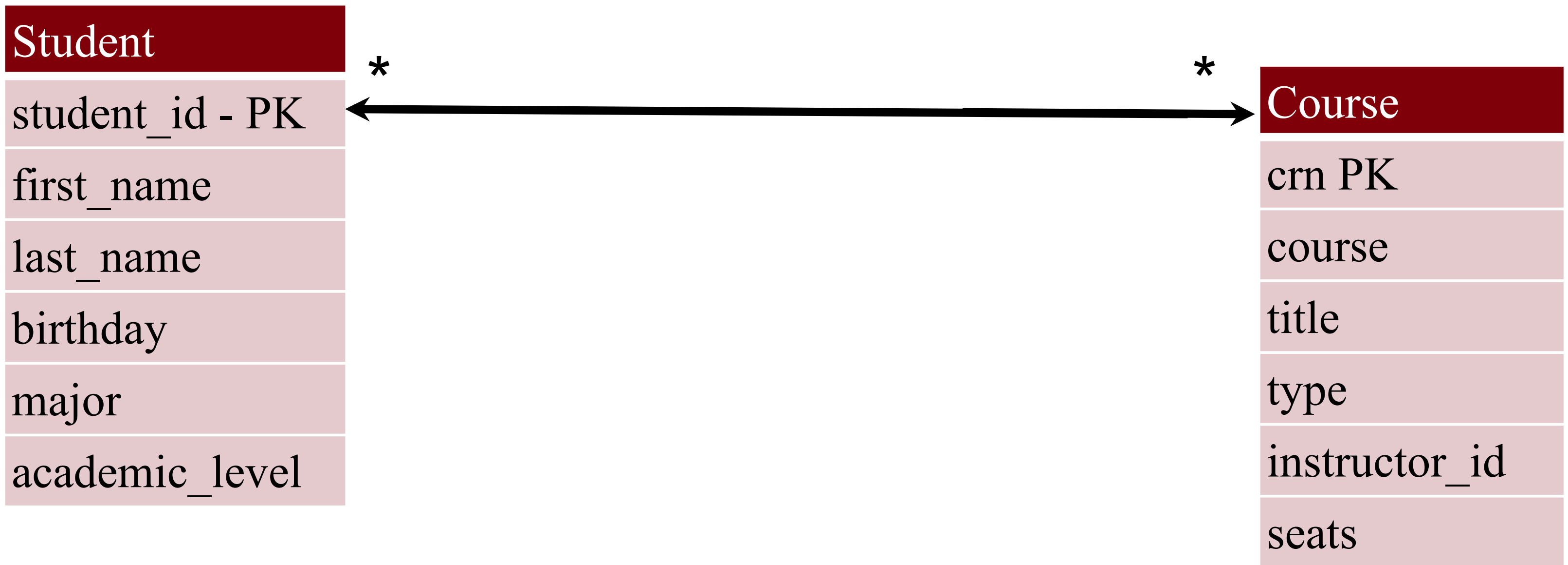
BigTable Data Model



https://thedigitalskye.com/2021/03/23/cloud-bigtable-what-is-it-and-why-might-we-need-it-one-day/

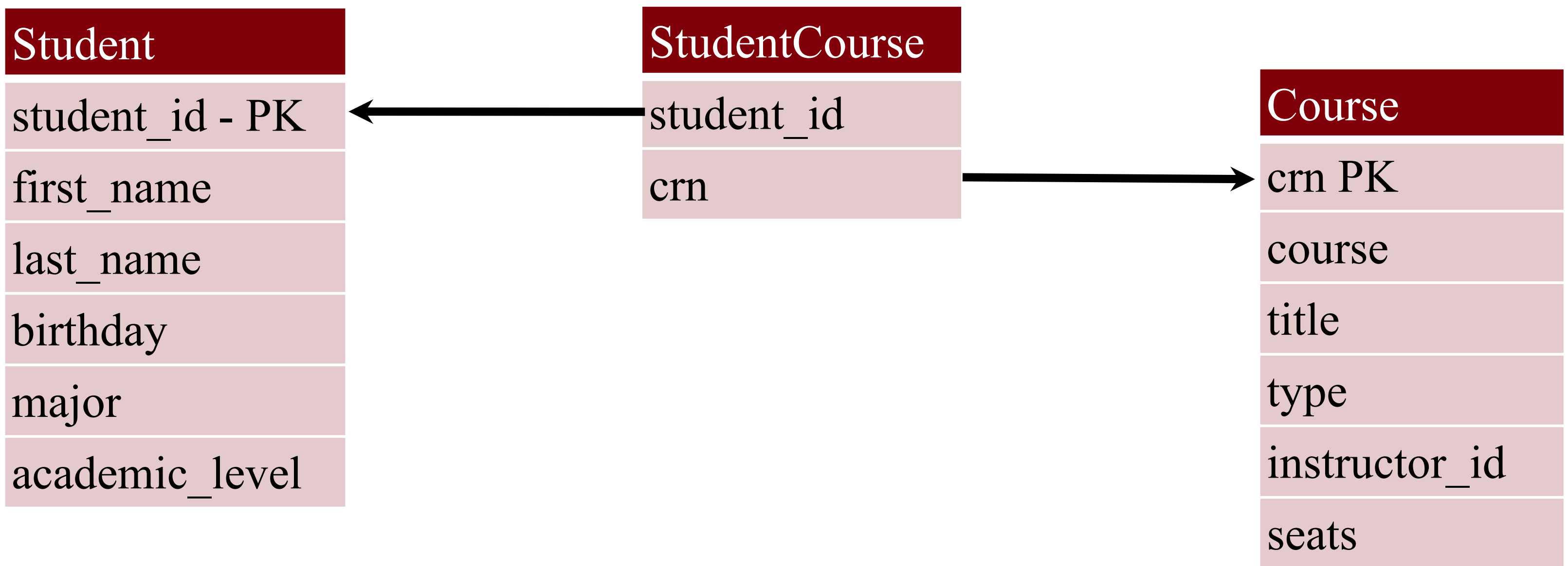
Relational vs BigTable

- Example:

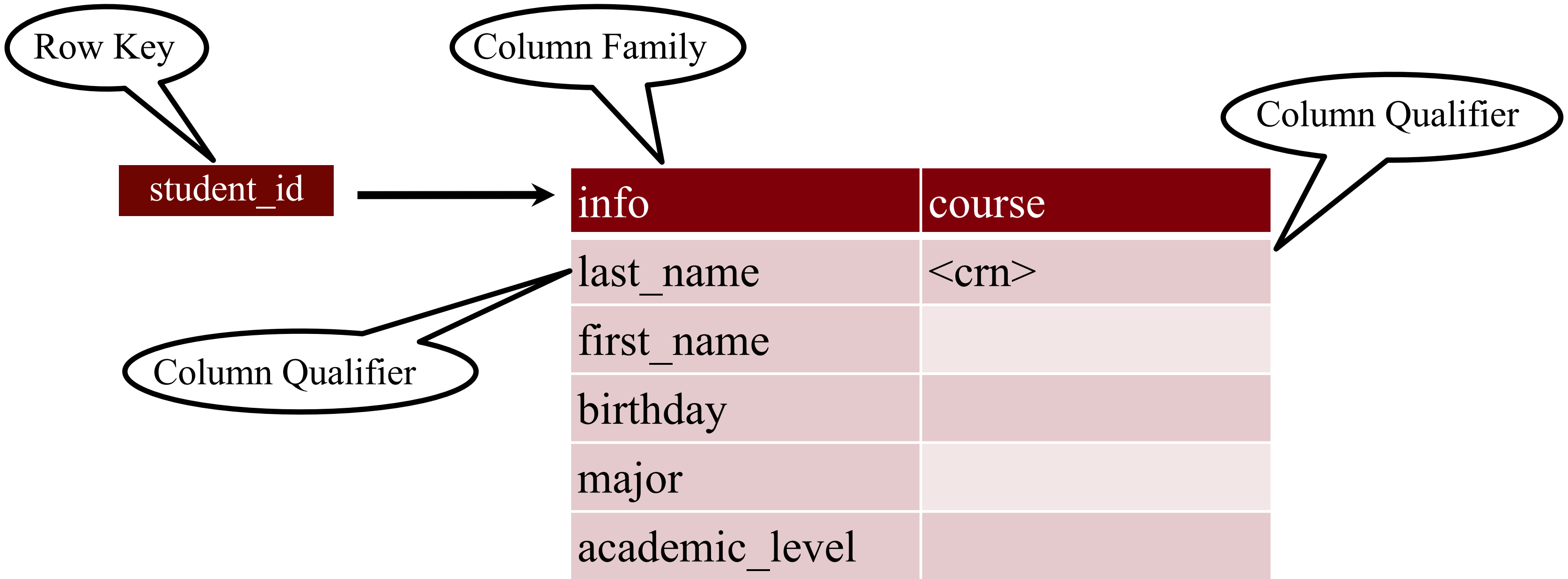


Relational vs BigTable

- Example:

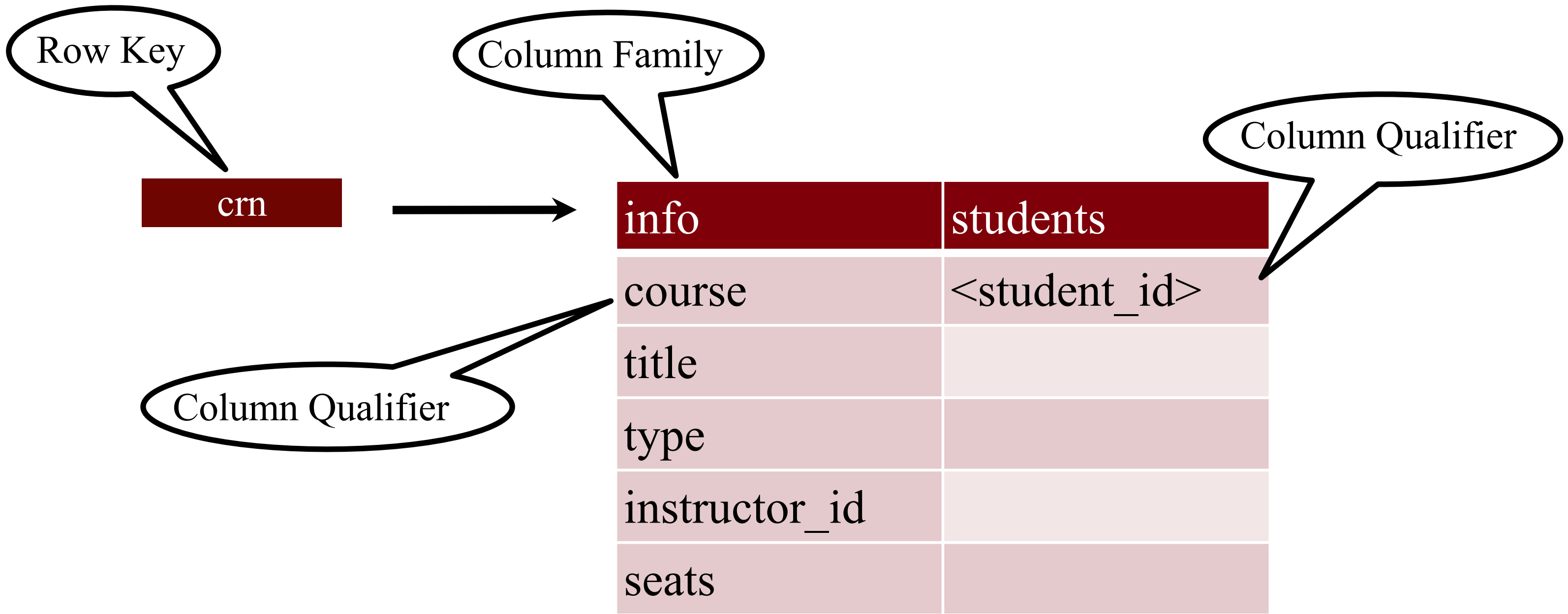


BigTable – Student table



	info:first_name	info:last_name	info:major	courses:96322	courses:96320
"905514"	"Sergejs"	"Melderis"	"Computer Science"	"YES"	"NO"

BigTable – Course table



	info:course	info:title	info:instructor_id	students:905514	students:905520
"96322" →	"CS5204"	"Operating Systems"	"1983943"	"YES"	"YES"

Example - Students data view in JSON

```
{ 905514: {
        info :  {
                first_name : { t1 : Sergejs  },
                last_name  : { t1 : Melderis },
                major : { t1 : Comp Science }
        },
        courses :  {
                96322: { t1 : “YES”  },
                96320: { t2 : “NO” }
        }
}
```

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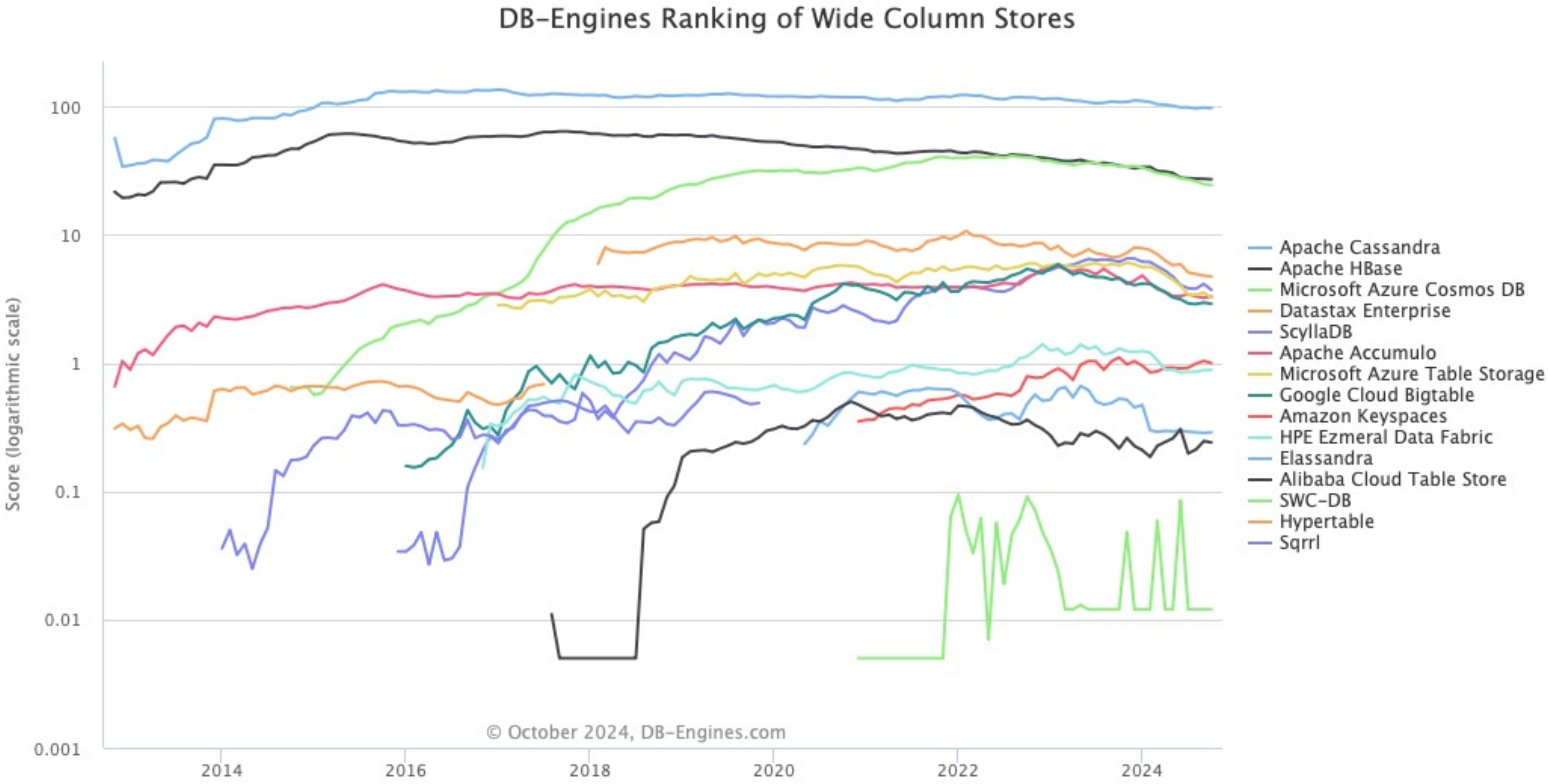
Apache Cassandra

Cassandra Ranking



https://db-engines.com/en/ranking_trend/wide+column+store

Cassandra Overview

- Features:
  - open-source, high availability, linear scalability, sharding (spanning multiple datacenters), peer-to-peer configurable replication, tunable consistency, MapReduce support
- Implemented in Java
- Cross-platform
- Originally developed by Facebook
  - open-sourced in 2008
- Adopted by Twitter, Rackspace, Netflix, eBay, GitHub, Instagram, etc.
- Developed by Apache Software Foundation
  - http://cassandra.apache.org/

History: Facebook Inbox Search

- Cassandra developed to address this issue
- Performance tested with more than 50TB of user messages data in a cluster of 150 nodes (2 data centers)
- Search index of all messages in 2 ways:
  - term search: search by a keyword
  - interactions search: search by a user id

Latency	Search Interactions	Search Term
Min	7.69 ms	7.78 ms
Median	15.69 ms	18.27 ms
Max	26.13 ms	44.41 ms

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Cassandra vs MySQL

- > 50 GB of Data

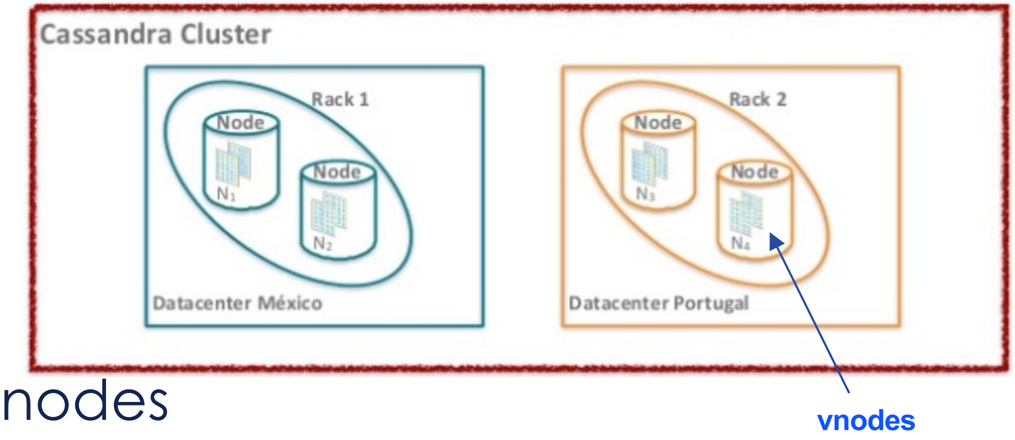
Average Time	MySQL	Cassandra
Write	~ 300 ms	0.12 ms
Read	~ 350 ms	15 ms

** facebook data / use case*

Motivations

- High Availability
- High Write Throughput
  - while not sacrificing read efficiency
- Fault Tolerance
- High and incremental scalability
- Reliability at a massive scale

Clusters, Data Centers, Nodes



- Node
  - a machine where Cassandra is running
- Data Center
  - A collection of related nodes
  - Synonymous of replication group
    - replication is set by data center
    - a grouping of nodes configured together for replication purposes
  - Using separate data centers allows:
    - dedicating each data center to different processing tasks
    - Satisfying requests from a data center close to the client
- Cluster
  - A collection of data centers
    - One database contains one or more clusters.

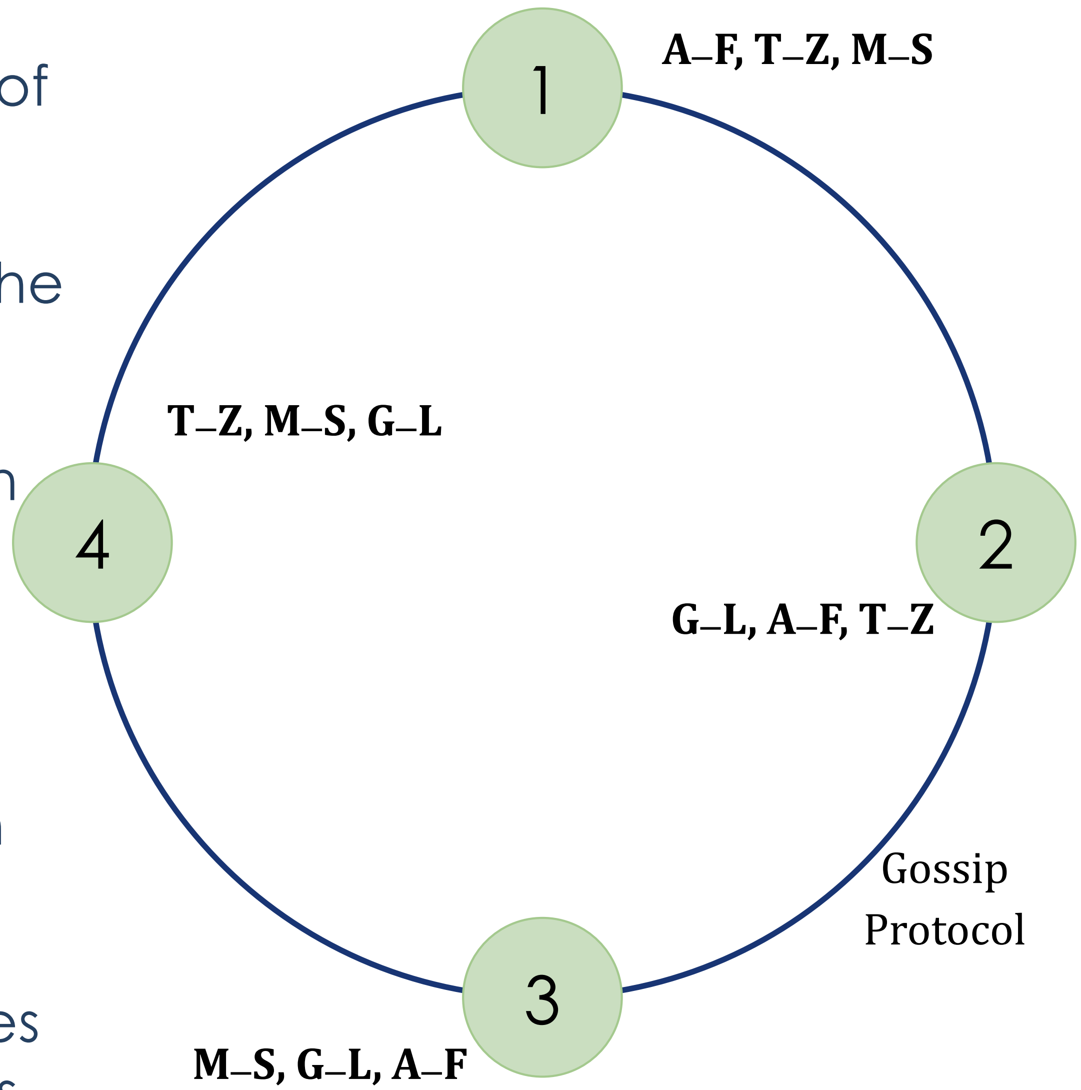
Cassandra – System Architecture

- Cluster Membership
  - how nodes are added, deleted to the cluster
- Partitioning
  - how data is partitioned across nodes
  - nodes are logically structured in Ring Topology
  - hashed value of key associated with data partition is used to assign it to a node in the ring
- Replication
  - how data is duplicated across nodes
  - each data item is replicated at N (replication factor) nodes

Note: Those topics will be discussed more in detail in the following lessons. In this phase, we will be only focusing on the data model.

Network Nodes Topology

- Data managed by a ring of nodes
- Each node has a part of the database
- Rows distribution based on primary key
  - row lookups are fast
- Multiples nodes have the same data to ensure both availability and durability
- No master node – all nodes can perform all operations



Data Model (keyspaces → tables → rows → columns)

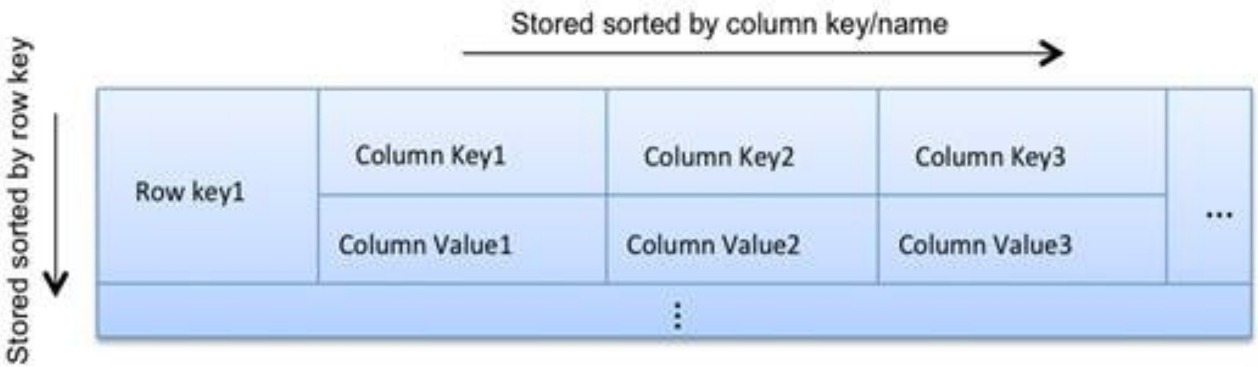
- Keyspace
  - a **namespace** that defines data replication on nodes
  - a cluster contains one keyspace per node
- Table (column family)
  - collection of (similar) rows
  - a multi dimensional map indexed by key (row key)
  - table schema must be specified but can be modified later
  - 2 types: simple or super (nested Column Families)
- Row
  - collection of columns
  - rows in a table do not need to have the same columns
  - each row is **uniquely identified** by a **primary key**
- Column
  - name-value pair + additional data

Data Model

Relational Model	Cassandra Model
Database	Keyspace
Table	Column Family (CF)
Primary key	Row key
Column name	Column name/key
Column value	Column value

A nested sorted map is an accurate analogy for each column family:

```
Map<RowKey, SortedMap<ColumnKey, ColumnValue>>
```



Data Model – Example

actors

id	
trojan	name: (Ivan, Trojan) · year: 1964 · movies: { samotari, medvidek }
machacek	name: (Jiří, Macháček) · year: 1966 · movies: { medvidek, vratnelahve, samotari }
schneiderova	name: (Jitka, Schneiderová) · year: 1973 · movies: { samotari }
sverak	name: (Zdeněk, Svěrák) · year: 1936 · movies: { vratnelahve }

movies

id	
samotari	title: Samotáři · year: 2000 · actors: null · genres: [comedy, drama]
medvidek	title: Medvídek · director: (Jan, Hřebejk) · year: 2007 · actors: { trojan: Ivan, machacek: Jirka }
vratnelahve	title: Vratné lahve · year: 2006 · actors: { machacek: Robert Landa }
zelary	title: Želary · year: 2003 · actors: {} · genres: [romance, drama]

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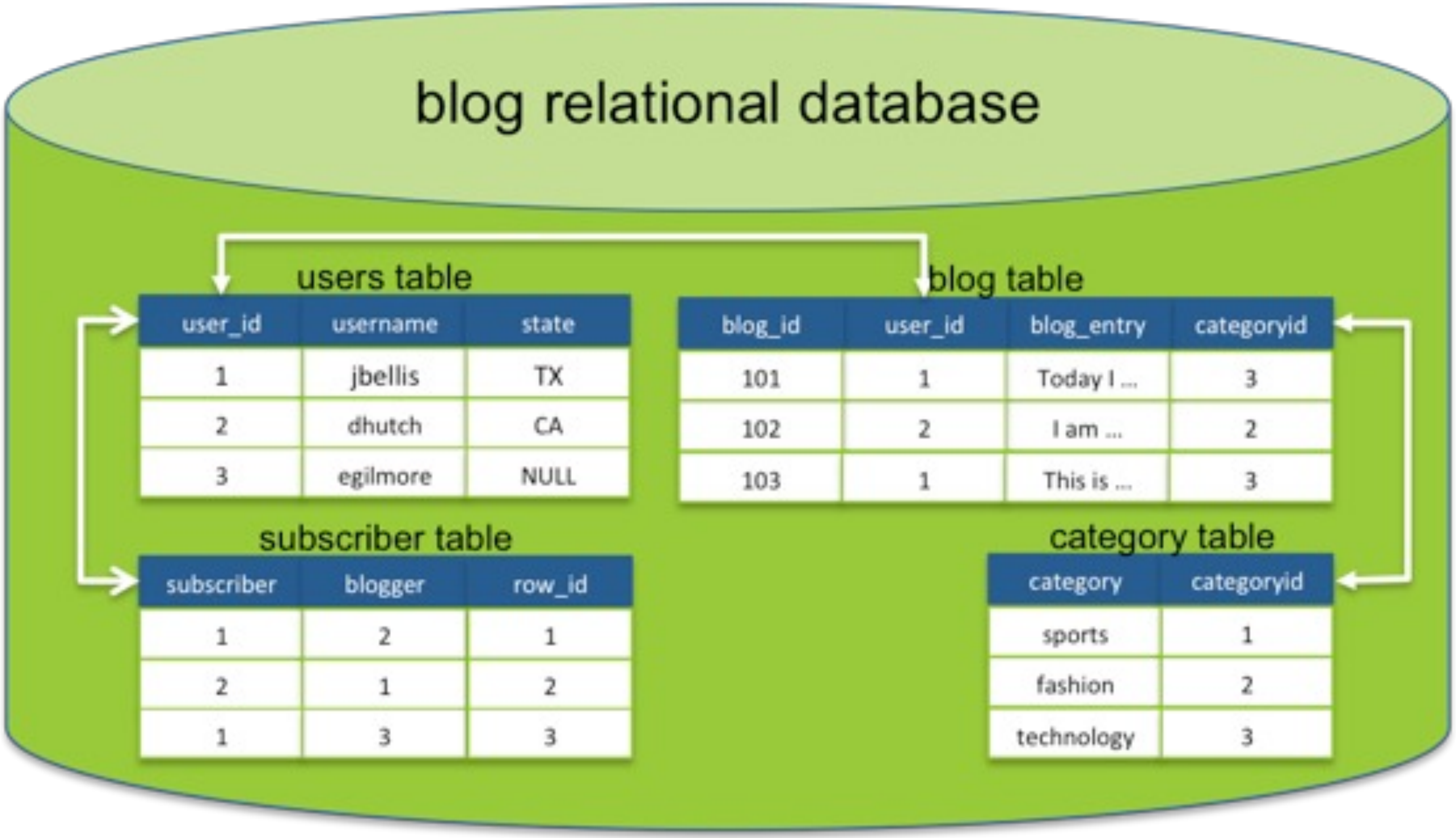
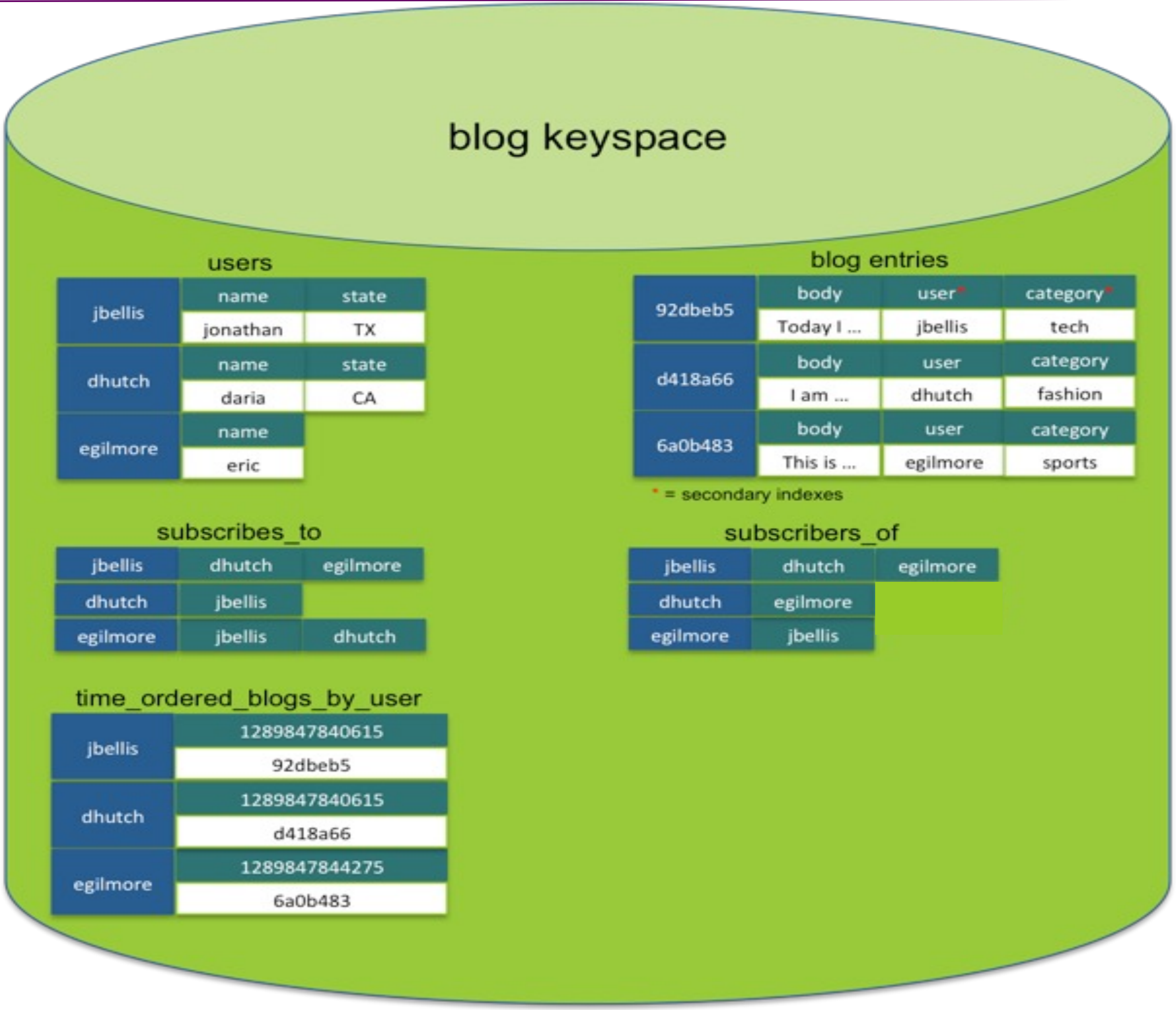
Cassandra vs Relational Example



Cassandra vs Relational Example



Data Model – Column Values

- Empty value
  - null
- Atomic value
  - **native** data **types**
    - texts, integers, dates, …
  - **tuples**
    - tuple of anonymous fields, each of any type (even different)
  - **user defined types** (UDT)
    - set of named fields of any type
- Collections
  - **lists**, **sets**, and **maps**
    - nested tuples, UDTs, or collections are allowed, but currently only in frozen mode (such elements are serialized when stored)

Data Model – Additional Data

- Associated with the whole column in case of atomic values, or every element of a collection

- **Time-to-live** (TTL)
  - after a certain amount of time (number of seconds) a given value is automatically deleted
- **Timestamp** (writetime)
  - timestamp of the last value modification
  - assigned automatically or manually as well

- Both elements can be queried
  - but not in case of collections and their elements

Cassandra API

- CQLSH
  - interactive command line shell
  - bin/cqlsh
  - uses CQL (Cassandra Query Language)

- Client drivers
  - provided by the community
  - available for various languages
    - Java, Python, Ruby, PHP, C++, Scala, Erlang, …

Cassandra Query Language (CQL)

- Declarative query language inspired by SQL
  - https://cassandra.apache.org/doc/latest/cql/
  - https://docs.datastax.com/en/cql/dse-6.9/overview/cql-about.html
- **DDL statements (Data Definition Lang.)**

  CREATE KEYSPACE – creates a new keyspace

  CREATE TABLE – creates a new table

  …
- **DML statements (Data Manipulation Lang.)**

  SELECT – selects and projects rows from a single table

  INSERT – inserts rows into a table

  UPDATE – updates columns of rows in a table

  DELETE – removes rows from a table

  …

Keyspace

- CREATE KEYSPACE

```
CREATE KEYSPACE [ IF NOT EXISTS ] keyspace_name WITH options
```

- Replication option is mandatory
  - SimpleStrategy
    - one replication factor for the whole cluster
  - NetworkTopologyStrategy
    - individual replication factor for each data center

```
CREATE KEYSPACE Excelsior
           WITH replication = {'class': 'SimpleStrategy', 'replication_factor' : 3};

CREATE KEYSPACE Excalibur
           WITH replication = {'class': 'NetworkTopologyStrategy', 'DC1' : 1, 'DC2' : 3}
            AND durable_writes = false;
```

Keyspace (cont)

- USE KEYSPACE

```
USE KEYSPACE
```

- DROP KEYSPACE

```
DROP KEYSPACE [ IF EXISTS ]
```

- ALTER KEYSPACE

```
ALTER KEYSPACE keyspace_name WITH options
```

```
ALTER KEYSPACE Excelsior
          WITH replication = {'class': 'SimpleStrategy', 'replication_factor' : 4};
```

Native Data Types

type	constants supported	description
ascii	string	ASCII character string
bigint	integer	64-bit signed long
blob	blob	Arbitrary bytes (no validation)
boolean	boolean	Either true or false
counter	integer	Counter column (64-bit signed value). See Counters for details
date	integer, string	A date (with no corresponding time value). See Working with dates below for details
decimal	integer, float	Variable-precision decimal
double	integer float	64-bit IEEE-754 floating point
duration	duration,	A duration with nanosecond precision. See Working with durations below for details
float	integer, float	32-bit IEEE-754 floating point
inet	string	An IP address, either IPv4 (4 bytes long) or IPv6 (16 bytes long). Note that there is no inet constant, IP address should be input as strings
int	integer	32-bit signed int
smallint	integer	16-bit signed int
text	string	UTF8 encoded string
time	integer, string	A time (with no corresponding date value) with nanosecond precision. See Working with times below for details
timestamp	integer, string	A timestamp (date and time) with millisecond precision. See Working with timestamps below for details
timeuuid	uuid	Version 1 UUID, generally used as a "conflict-free" timestamp. Also see Timeuuid functions
tinyint	integer	8-bit signed int
uuid	uuid	A UUID (of any version)
varchar	string	UTF8 encoded string
varint	integer	Arbitrary-precision integer

Table – Create Statement

- CREATE TABLE
  - creates a new table within the current keyspace
  - each table must have one primary key specified

```
CREATE TABLE [ IF NOT EXISTS ] table_name
        '(' column_definition ( ',' column_definition )*
           [ ',' PRIMARY KEY '(' primary_key ')' ]
        ')'
        [ WITH table_options ]

column_definition ::= column_name cql_type [ STATIC ] [ PRIMARY KEY]
primary_key ::= partition_key [ ',' clustering_columns ]
  partition_key ::= column_name|'('column_name( ',' column_name )*')'
  clustering_columns ::= column_name ( ',' column_name )*
table_options ::= COMPACT STORAGE [ AND table_options ] | CLUSTERING
ORDER BY '(' clustering_order ')' [ AND table_options ] | options
clustering_order ::= column_name (ASC | DESC) ( ',' column_name (ASC |
DESC) )*
```

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Table Primary Key

Primary key has two parts:

- Compulsory **partition key**
  - single column or multiple columns
  - describes how table rows are distributed among partitions
- Optional **clustering columns**
  - defines the clustering order, i.e. how table rows are locally stored within a partition

```
CREATE TABLE groups (
    groupname text,
    username text,
    email text,
    age int,
    PRIMARY KEY (groupname, username)
)
```

PRIMARY KEY has two components: **groupname**, which is the **partitioning key**, and **username**, which is called the **clustering key**. This will give us one partition per groupname. Within a particular partition (group), rows will be ordered by username.

Keys Roles

- **Partition Key**
  - responsible for data partitioning across database nodes
- **Clustering Key**
  - responsible for data sorting within the partition
- **Primary Key**
  - **Partition Key + Clustering Key**
  - is equivalent to the **Partition Key** in a single-field-key table
- **Composite Key**
  - partition and clustering key can have multiple-columns

```
create table mytable (
      k_part_one text,
      k_part_two int,
      k_clust_one text,
      k_clust_two int,
      k_clust_three uuid,
      data text,
      PRIMARY KEY((k_part_one,k_part_two), k_clust_one, k_clust_two, k_clust_three)
  );
```

Data Storage and the Keys Roles

```
CREATE TABLE numberOfRequests (
    cluster text,
    date text,
    datacenter text,
    hour int,
    minute int,
    numberOfRequests int,
    PRIMARY KEY ((cluster, date), datacenter, hour, minute))
```

- <u>cluster</u> and <u>date</u> fields define the partition (node) where the row is stored

- Inside the partition, every row will be stored like this:

```
{datacenter: US_WEST_COAST {hour: 0 {minute: 0 {numberOfRequests: 130}} {minute: 1 {numberOfRequests: 125}} …
                                     {minute: 59 {numberOfRequests: 97}}}
                           {hour: 1 {minute: 0 …
```

Create Table Examples

```
CREATE TABLE postsbyuser (
  userid bigint,
  posttime timestamp,
  postid uuid,
  postcontent text,
  PRIMARY KEY ((userid), posttime)
) WITH CLUSTERING ORDER BY (posttime DESC);
```

```
CREATE TABLE timeline (
    userid uuid,
    posted_month int,
    posted_time uuid,
    body text,
    posted_by text,
    PRIMARY KEY (userid, posted_month, posted_time)
) WITH compaction = { 'class' : 'LeveledCompactionStrategy' };
```

```
CREATE TABLE movies (
  id TEXT,
  title TEXT,
  director TUPLE<TEXT, TEXT>,
  year SMALLINT,
  actors MAP<TEXT, TEXT>,
  genres LIST<TEXT>,
  countries SET<TEXT>,
  PRIMARY KEY (id)
)
```

Table – Other Statements

- DROP TABLE

```
DROP TABLE [ IF EXISTS ] table_name
```

- TRUNCATE TABLE
  - preserves a table but removes all data it contains

```
TRUNCATE [ TABLE ] table_name
```

- ALTER TABLE

```
ALTER [ TABLE ] table_name alter_table_instruction

alter_table_instruction ::= ADD column_name cql_type ( ',' column_name
cql_type )* | DROP column_name ( column_name )* | WITH options
```

```
ALTER TABLE addamsFamily ADD gravesite varchar;
```

Select Statement

- Reads one or more columns for 1+ rows in a table

```
SELECT [ JSON | DISTINCT ] ( select_clause | '*' )
FROM table_name
[ WHERE where_clause ]
[ GROUP BY group_by_clause ]
[ ORDER BY ordering_clause ]
[ PER PARTITION LIMIT (integer | bind_marker) ]
[ LIMIT (integer | bind_marker) ]
[ ALLOW FILTERING ]
```

- Clauses

  SELECT – columns or values to appear in the result

  FROM – single table to be queried

  WHERE – filtering conditions to be applied on table rows

  GROUP BY – columns used for grouping of rows

  ORDER BY – criteria defining the order of rows in the result

  LIMIT – number of rows to be included in the result

Select – FROM Clause

- Defines a **single table** to be queried
  - from the current / specified keyspace
  - joining of multiple tables is not possible
- Supports:
  - **distinct** to remove duplicate rows
  - (user-defined) **aggregate functions**
  - ***** to select all columns; and attributes **alias** (AS)
  - WRITETIME (**timestamp**) and TTL (**time-to-live**) of a column
    - cannot be used in WHERE clause

```
SELECT name, occupation FROM users WHERE userid IN (199, 200, 207);
SELECT JSON name, occupation FROM users WHERE userid = 199;
SELECT name AS user_name, occupation AS user_occupation FROM users;

SELECT time, value
FROM events
WHERE event_type = 'myEvent'
  AND time > '2011-02-03'
  AND time <= '2012-01-01'

SELECT COUNT (*) AS user_count FROM users;
```

```
select videoname, ttl(videoname), writetime(videoname) from videos;

 videoname                 | ttl(videoname) | writetime(videoname)
---------------------------+----------------+----------------------
    Ondas gigantes na barra! |           null |     1509294890781000
         Aviões de papel! |           null |     1509294888607000
```

Select – WHERE Clause

- **Similar syntaxes**: **CQL** and **SQL**

- **Several differences** because Cassandra deals with distributed data and aims to prevent inefficient queries
  - rows are spread around the cluster based on the hash of the partition keys
  - clustering key columns are used to cluster the data of a partition, allowing a very efficient retrieval of rows

- Partition key, clustering and normal columns support different sets of restrictions within the WHERE clause

Select – WHERE Clause

- **Partition key** columns support only **=** and **IN**
  - all primary key columns must be used (restricted), unless secondary index exist
    - all columns are needed to compute the hash that will allow it to locate the nodes containing the partition

- **Clustering columns** supports:
  - comparisons =, <, <=, =>, >
  - **IN**, returns true if the actual value is one of the enumerated
  - **CONTAINS*** and **CONTAINS KEY****
    - used on collections* (lists, sets, and maps) / maps**
    - returns true if a collection contains a given element, or, when the query is using a secondary index

Select – WHERE: Examples 1

```
CREATE TABLE numberOfRequests (
    cluster text,
    date text,
    datacenter text,
    hour int,
    minute int,
    numberOfRequests int,
    PRIMARY KEY ((cluster, date), datacenter, hour, minute))
```

```
/*  Data will be stored like this:
{datacenter: US_WEST_COAST {hour: 0 {minute: 0 {numberOfRequests: 130}} {minute: 1 {numberOfRequests: 125}} …
                                    {minute: 59 {numberOfRequests: 97}}}
                           {hour: 1 {minute: 0 …
*/
```

```
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND datacenter = 'US_WEST_COAST'
    AND hour = 14
    AND minute = 00;
```

```
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND hour = 14
    AND minute = 00;
```

```
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND hour = 14
    AND minute = 00;
```

```
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND hour IN (14, 15)
    AND minute = 0;

SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND (hour, minute) IN ((14, 0), (15, 0));

-- multi-column IN restrictions can be applied to any set of clustering columns.
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND (datacenter, hour) IN (('US_WEST_COAST', 14), ('US_EAST_COAST', 17))
    AND minute = 0;
```

Select – WHERE: Examples 2

```
>, >=, <= and < restrictions
Single column slice restrictions are allowed only on the last clustering column being restricted.
Multi-column slice restrictions are allowed on the last set of clustering columns being restricted.
```

```
-- OK
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND hour= 12
    AND minute >= 0 AND minute <= 30;

-- OK
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND hour >= 12;

-- OK
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter > 'US';


-- NOK
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND hour >= 12 AND minute = 0;
```

```
CREATE TABLE numberOfRequests (
    cluster text,
    date text,
    datacenter text,
    hour int,
    minute int,
    numberOfRequests int,
    PRIMARY KEY ((cluster, date), datacenter, hour, minute))
```

```
-- OK
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND (hour, minute) >= (12, 0) AND (hour, minute) <= (14, 0)

-- OK
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND (hour, minute) >= (12, 30) AND (hour) <= (14)


-- NOK: the restrictions must start with the same column
SELECT * FROM numberOfRequests
    WHERE cluster = 'cluster1'
    AND date = '2015-06-05'
    AND datacenter = 'US_WEST_COAST'
    AND (hour, minute) >= (12, 30) AND (minute) <= (30)
```

Select – WHERE: Secondary Index

- Direct queries on secondary indices support only **=**, **CONTAINS** or **CONTAINS KEY** restrictions

```
CREATE TABLE contacts (
    id int PRIMARY KEY,
    firstName text,
    lastName text,
    phones map<text, text>,
    emails set<text>
);
```

```
select * from contacts
where firstname = 'Maria';
```

```
/*
    Solution: Secondary Index
*/
CREATE INDEX ON contacts (firstName);
-- Using the keys function to index the map keys
CREATE INDEX ON contacts (keys(phones));
CREATE INDEX ON contacts (emails);
```

```
SELECT * FROM contacts WHERE firstname = 'Benjamin';
SELECT * FROM contacts WHERE phones CONTAINS KEY 'office';
SELECT * FROM contacts WHERE emails CONTAINS 'Benjamin@oops.com';
```

Select – GROUP BY, ORDER BY and LIMIT

- **GROUP BY** clause
  - groups rows of a table according to certain columns
  - only groupings induced by primary key columns are allowed
  - when a non-grouping column is selected without an aggregate function, the first value encounter is always returned
- **ORDER BY** clause
  - defines the order (ASC or DESC) of returned rows
  - partition key must be restricted (= or IN)
  - only orderings induced by clustering columns are allowed!
- **LIMIT** clause
  - limits the number of rows returned in the query result

Select – Group and Order By Examples

```
CREATE TABLE contacts (
    type text,
    id int,
    firstName text,
    lastName text,
    phones map<text, text>,
    emails set<text>,
    PRIMARY KEY(type, id)
);
```

```
select * from contacts
where id = 33
order by id;
```

```
select * from contacts
where type = 'personal'
and id = 33
order by id;
```

```
select * from contacts
where type = 'personal'
group by type;
```

```
select * from contacts
where type = 'personal'
group by id;
```

only the first record is returned

```
select count(*) from contacts
group by type;
```

```
select count(*) from contacts
group by id;
```

Select – User Defined Functions

- User-Defined Functions (UDF)
  - allow the execution of user-provided code (Java or JavaScript)
  - Statements: CREATE (or REPLACE) /DROP FUNCTION

```
CREATE FUNCTION IF NOT EXISTS akeyspace.fname(someArg int)
    CALLED ON NULL INPUT
    RETURNS text
    LANGUAGE java
    AS $$
        // some Java code
    $$;
```

```
CREATE FUNCTION IF NOT EXISTS div (n counter, d counter)
   CALLED ON NULL INPUT
   RETURNS double
   LANGUAGE java AS '
     return Double.valueOf(n/d);
     ';

select rating_counter, div(rating_total, rating_counter)
from ...
```

Select – Aggregates

- Native
  - COUNT(column), MIN(column), MAX(column), SUM(column) and AVG(column)
- User-Defined Aggregate Function (UDA)
  - creation of custom aggregate functions

1

```
CREATE TABLE team_average (
   team_name text,
   cyclist_name text,
   cyclist_time_sec int,
   race_title text,
   PRIMARY KEY (team_name, race_title,cyclist_name)
);
```

2

```
-- UDF: adds all the race times together and counts the number of entries.
CREATE OR REPLACE FUNCTION avgState ( state tuple<int,bigint>, val int )
CALLED ON NULL INPUT
RETURNS tuple<int,bigint>
LANGUAGE java AS
$$ if (val !=null) {
      state.setInt(0, state.getInt(0)+1);
      state.setLong(1, state.getLong(1)+val.intValue());
      }
   return state; $$
;
```

3

```
-- UDF: computes the average of the values passed to it from the state function
CREATE OR REPLACE FUNCTION avgFinal ( state tuple<int,bigint> )
CALLED ON NULL INPUT
RETURNS double
LANGUAGE java AS
  $$ double r = 0;
     if (state.getInt(0) == 0) return null;
     r = state.getLong(1);
     r/= state.getInt(0);
     return Double.valueOf(r); $$
;
```

4

```
-- UDA: calculate the average
--       value in the column
CREATE AGGREGATE average(int)
SFUNC avgState
STYPE tuple<int,bigint>
FINALFUNC avgFinal
INITCOND (0,0);
```

5

```
-- Test the function using a select statement
SELECT average(cyclist_time_sec) FROM team_average
WHERE team_name='UnitedHealthCare'
AND race_title='Amgen Tour';
```

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Select – ALLOW FILTERING

- Option used to explicitly allow (some) queries that require filtering
- By default, only non-filtering queries are allowed
  - i.e. queries where the number of rows read ~ the number of rows returned
    - such queries have predictable performance
    - execution time that is proportional to the amount of data returned

```
CREATE TABLE users (
    username text PRIMARY KEY,
    firstname text,
    lastname text,
    birth_year int,
    country text
)

CREATE INDEX ON users(birth_year);
```

```
SELECT * FROM users;
SELECT * FROM users WHERE birth_year = 1981;
```

```
SELECT * FROM users WHERE birth_year = 1981 AND country = 'FR';
```

```
SELECT * FROM users WHERE birth_year = 1981 AND country = 'FR' ALLOW FILTERING;
```

Insert Statement

- Inserts a new row into a given table
  - if the primary key already exists, the row is updated
  - IF NOT EXISTS condition to only insert if row does not exist
- Writes one or more columns for a given row
- At least primary key columns must be specified

```
INSERT INTO NerdMovies (movie, director, main_actor, year)
                VALUES ('Serenity', 'Joss Whedon', 'Nathan Fillion', 2005)
      USING TTL 86400;

INSERT INTO NerdMovies JSON '{"movie": "Serenity",
                              "director": "Joss Whedon",
                              "year": 2005}';
```

```
CREATE TABLE movies (
  id TEXT,
  title TEXT,
  director TUPLE<TEXT, TEXT>,
  year SMALLINT,
  actors MAP<TEXT, TEXT>,
  genres LIST<TEXT>,
  countries SET<TEXT>,
  PRIMARY KEY (id)
)
```

```
INSERT INTO movies (id, title, director, year, actors, genres)
VALUES (
  'stesti',
  'Štěstí',
  ('Bohdan', 'Sláma'),
  2005,
  { 'vilhelmova': 'Monika', 'liska': 'Toník' },
  [ 'comedy', 'drama' ]
)
USING TTL 86400
```

Update Statement

- Updates existing rows within a given table
  - when a row with a given primary key does not yet exist, it is inserted
- All primary key columns must be specified in the WHERE clause

```
UPDATE NerdMovies USING TTL 400
   SET director   = 'Joss Whedon',
       main_actor = 'Nathan Fillion',
       year       = 2005
 WHERE movie = 'Serenity';

UPDATE UserActions
   SET total = total + 2
   WHERE user = B70DE1D0-9908-4AE3-BE34-5573E5B09F14
     AND action = 'click';
```

Update Statement – More Examples

```
UPDATE movies
SET
  year = 2006,
  director = ('Jan', 'Svěrák'),
  actors = { 'machacek': 'Robert Landa', 'sverak': 'Josef Tkaloun' },
  genres = [ 'comedy' ],
  countries = { 'CZ' }
WHERE id = 'vratnelahve'
```

```
UPDATE movies
SET
  actors = actors + { 'vilhelmova': 'Helenka' },
  genres = [ 'drama' ] + genres,
  countries = countries + { 'SK' }
WHERE id = 'vratnelahve'
```

```
UPDATE movies
SET
  actors['vilhelmova'] = 'Helenka',
  genres[1] = 'comedy'
WHERE id = 'vratnelahve'
```

```
CREATE TABLE movies (
  id TEXT,
  title TEXT,
  director TUPLE<TEXT, TEXT>,
  year SMALLINT,
  actors MAP<TEXT, TEXT>,
  genres LIST<TEXT>,
  countries SET<TEXT>,
  PRIMARY KEY (id)
)
```

Insert and Update Parameters

- **TTL**: time-to-live
  - 0 or null or simply missing for persistent values
  - if set, the inserted values are automatically removed from the database after the specified time.

- **TIMESTAMP**: writetime
  - only newly inserted / updated values are really affected
  - if not specified, it will be used the current time (in microseconds)

```
UPDATE user USING TTL 3600 SET last_name = 'McDonald'
WHERE first_name = 'Mary';

SELECT first_name, last_name, TTL(last_name)
FROM user WHERE first_name ='Mary';

 first_name | last_name   | ttl(last_name)
------------+-------------+---------------
  Mary      |  McDonald   |           3588
```

```
INSERT INTO cycling.comments (
    id,
    created_at)
values (
    123456,
    toTimeStamp(now()));
```

Delete Statement

- Removes existent rows / columns / collection elements from a given table
- **WHERE** clause specifies which rows are to be deleted
- Multiple rows may be deleted with one statement by using an **IN** operator.
- A range of rows may be deleted using an inequality operator (such as >=)

```
DELETE FROM NerdMovies USING TIMESTAMP 1240003134
 WHERE movie = 'Serenity';

DELETE phone FROM Users
 WHERE userid IN (C73DE1D3-AF08-40F3-B124-3FF3E5109F22, B70DE1D0-9908-4AE3-BE34-5573E5B09F14);
```

Java Driver

- Driver:
  - Datastax
    - https://github.com/datastax/java-driver
    - com.datastax.driver.core
  - required JARs
    - cassandra-driver-core-...
    - slf4j-api-...
    - guava-...
    - metrics-core-...
    - netty-all-...
- Documentation
  - http://docs.datastax.com/en/developer/java-driver
  - http://docs.datastax.com/en/drivers/java/
  - https://www.tutorialspoint.com/cassandra/cassandra_installation.htm

Summary

- Column-oriented databases
- Google BigTable
- Apache Cassandra
  - Data Model
  - Cassandra query language
    - DDL statements
    - DML statements
  - CRUD operations
  - UDF
- Cassandra Java driver

Resources

- Martin Kleppmann, ***Designing Data-Intensive Applications***, O'Reilly Media, Inc., 2017.
- Eben Hewitt, Jeff Carpenter, **Cassandra: The Definitive Guide**, 2nd Edition - Distributed Data at Web Scale, O'Reilly Media, Inc., 2016.
- Christof Strauch. **NoSQL Databases**, 2009.

- Cassandra Tutorials/Documentation:
  - https://www.tutorialspoint.com/cassandra/
  - https://www.datastax.com/resources/tutorials
  - https://teddyma.gitbooks.io/learncassandra/
  - https://cassandra.apache.org/doc/latest/
  - http://docs.datastax.com/en/dse/5.1/cql/
  - https://cassandra.apache.org/doc/latest/cql/